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A new layout of HTS tapes and their critical currents for DC power cables

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Abstract

We investigated the gap effects on the critical current of the middle tape in the paralleled arrangements of three straight BSCCO tapes with monolayer, 2-layer and 3-layer structures to improve the cable superconducting performance by the tape arrangement. The critical current of the BSCCO tape increases with the decreasing of the gap for the monolayer structure, increases by 11% for the 2-layer and decreases by 15% for the 3-layer structure. A new layout of HTS tapes for the DC power cable is presented. The critical current of the BSCCO tape in a cable with a new layout may increase by 10%.

Keywords: HTS cable; Critical current; BSCCO; DC transmission; Gap effect

1. Introduction

The DC superconducting power transmission (SC-PT) system has been studied at Chubu University for being free from of AC losses [1]. In the DC SC-PT system, the coaxial cable is used and the high temperature superconducting (HTS) tapes are spirally and closely wounded along a former as two conductors for each polarity of the DC electric power [2]. The number of the tapes in each conductor is different because of their different radii. In order to make the magnetic flux line circular around the cable, the HTS tapes are wounded as close as possible. However, the gap can not be avoided by using the tape conductors for their polygonal shape [3]. If the same number of the same tapes are used for each conductor, additional space between the tapes will be produced because of the different circumference of each layer.

The property of the HTS tapes in the HTS cable is affected by their configurations such as gaps and layer-structures [4]. In the AC HTS cable, the gap effect are studied to reduce the AC losses [5]. The critical current of a tape in the cable is affected by the external field from the other tapes recently reported by Hamabe et al. [6]. Previously, we investigated the gap effects on the critical current of the tape in the triple paralleled arrangements of three straight BSCCO tapes with a mono-layer structure to optimize the

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layout of the HTS tapes in the cable. In the case of mono-layer structure, the critical current increases with the decreasing of the gap and would be enhanced for close winding [7]. On the other hand, the multi-layer structure is necessary for high current capacity transmission. The gap for each layer and the relative position are important parameters for the tape winding in the cable with the multi-layer structures.

In this technical report, the measurement of the critical current against the gap is continued by varying the lateral position for the multi-layer structures. We consider a new layout of HTS tapes for the DC power cable through the experiment. The critical current of a tape in the cable with new layout is tested. Through the experiments, we investigate the design of DC HTS power cables to improve the cable property by the tape arrangements.

2. Experiments

The DI-BSCCO® tapes (Type HT-CA) are used in the experiment [8, 9]. The cross section of the tape is 4.5 mm × 0.35 mm with 0.05 mm copper laminated layer on both sides of the tape [9]. The critical current of the BSCCO tape is 160 A in the self field at 77 K.

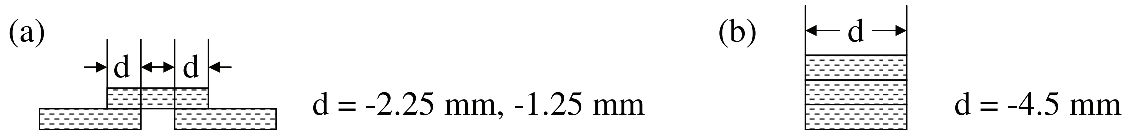

Fig. 1: A diagram of the arrangements of three HTS tapes for (a) 2-layer and (b) 3-layer with different gaps.

The setup of the critical current measurement is similar with that in the previous report [7]. The samples with the length of ∼ 27 mm are prepared in consideration as an infinitely long wire and surrounded with one Kapton tape layer for insulation with each other. Three voltage taps are soldered on each tape with space of 8 and 10 cm. The voltage signals are measured by a KEITHLEY 2700 multimeter. The I - V curves are measured by the standard four-probe method at the temperature of 77.3 K. The current is fed into three tapes in series mode. Figs. 1a and b show the arrangements of three HTS tapes for 2-layer and 3-layer structure with different lateral space gaps. d is the distance between the edges of the tapes. There is a gap of 2 mm between the tapes in the second layer for $d = -1.25$ mm and no gap for $d = -2.25$ mm as in Fig.1a.

3. Results and discussion

The E - I characteristic curves of the BSCCO tape are obtained by normalizing the voltages to the distance between the voltage taps. Fig. 2a shows comparisons of E-I curves of a BSCCO tape for single and triple arrangements with different gaps. The critical current is determined at the electric field criterion of 1 μV/cm. Fig. 2b summarizes the critical currents of the BSCCO tape with respect to the gap between the tapes in the 2-layer and 3-layer structures together with the mono-layer structures as in the previous report [7]. The critical current of single tape is measured to be 166 A. In the case of 2-layer structure, the critical current of the middle tape becomes larger than that of the single one. When $d = -1.25$ mm, the critical current increases by 11% to 184 A compared with the single one. The critical current of a tape in the 2-layer structure becomes maximum even if there is a gap between the tapes in the second layer. However, the critical current of the BSCCO tape decreases sharply by 17% to 137 A for the 3-layer structure.

The magnetic field distributions are calculated by the commercial finite element method code (ANSYS) [10, 11, 12]. To illustrate the effect of the self-field from the current by the neighboring tapes, Figs. 3 a - d present the magnetic flux lines for single and triple tape arrangement in the 2-layer and 3-layer structure with different gaps, respectively. The transport current of 160 A in each tape is assumed to be uniformly distributed in the cross section of the Ag-sheathed BSCCO filaments zone. Hence the cross section of the transport current area is assumed to be 4.5 mm × 0.25 mm without the laminated copper layer [9]. For 2-layer structure, the flux lines become flat and loose. When the gap is −1.25 mm, the magnetic flux lines

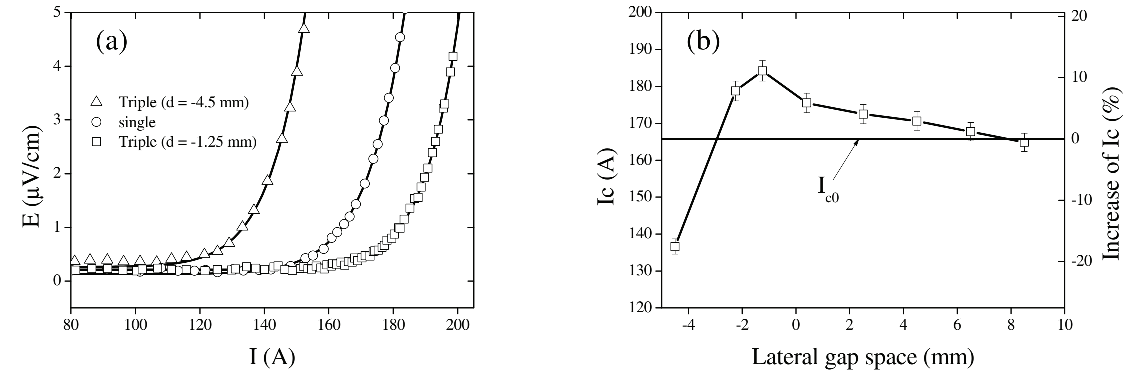

Fig. 2: (a) The E - I curves of the BSCCO tape for single and triple arrangements with d of −4.5 mm and −1.25 mm. (b) The dependence of I_c of the DI-BSCCO tape on the gap between the tapes.

are almost parallel to the tape wide surface of the middle tape as Fig. 3b, which results in the reduction of the perpendicular component of the magnetic field. Therefore, the critical current becomes maximum.

Through the measurements and calculations, we could optimize the tapes arrangement in the cable. Figure 4 shows a new layout of the cross section configuration of the tapes for a 2 kA DC HTS cable together with the present one. The inner diameter of the inner and outer conductor for both configurations are same, i.e., 18 mm and 26 mm, respectively. In the case of present cable, 16 and 23 tapes are spirally wounded as close as possible around a supporter with small gaps (< 0.5 mm) between the tapes for the outer and inner conductor. In the optimized cable, 16 tapes for the outer conductor is wounded as present one. 18 tapes are used for the inner conductor and arranged in the 2-layer structure. The gaps between the tapes for the inner and outer layer of the inner conductor is 1.9 and 2.2 mm because of the different diameter of each layer.

Figure 5a shows a diagram of three insulated tapes spirally winding around a supporter with a diameter of 2.6 cm and the twist pitch is around 25 cm. The same current flows through the three 54-cm-long BSCCO tapes. As shown in the cross-sectional view, there is a gap of 2 mm between two tapes in the inner layer close to the supporter. The measured $E - I$ curves of the tape in the cable is shown in Fig. 5b. Compared with single one, the critical current increases by 10% to 182 A and hence could be improved by optimizing the tape arrangements in the DC HTS power cable.

4. Conclusion

We have investigated the dependence of critical current of the BSCCO tapes on the lateral space gap between the tapes in the three straight paralleled tapes with the 2-layer and 3-layer structures. Critical current of a BSCCO tape is improved by arranging relative position in the 2-layer structures. However,

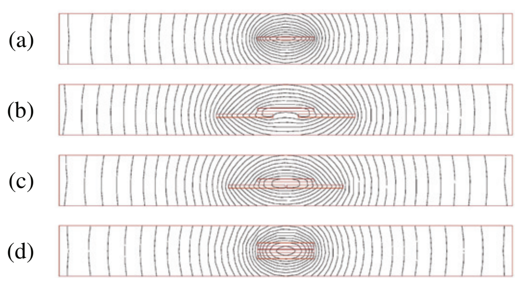

Fig. 3: The calculated magnetic flux lines for single (a) and triple arrangements (b-d) with 160 A in each tape.

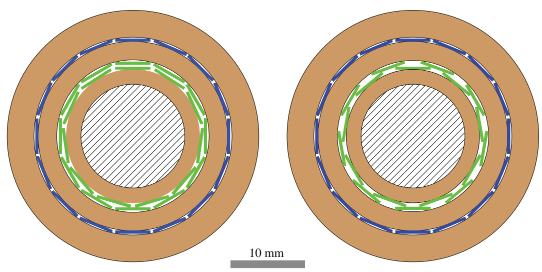

Fig. 4: A scheme of the cross section configuration of the tapes for 2 kA DC HTS cable.

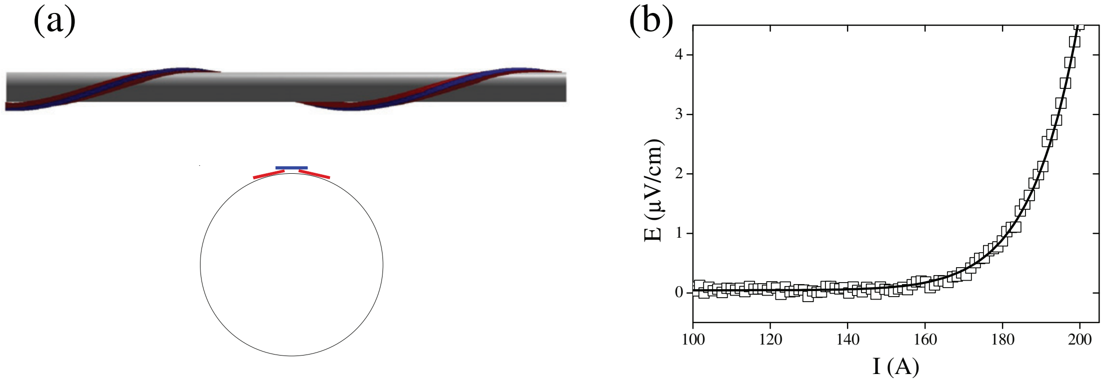

Fig. 5: (a) Three DI-BSCCO tapes helically surrounding a supporter with 2-layer structure with the gap 2 mm in the second layer as the cross section image in the insert. (b) $E - I$ characteristics of a tape in the cable winding.

critical current is degraded in the 3-layer structure with a tape-on-tape stack arrangement. Through the experiments and calculations, a new layout of the cable configuration is given, which may improve the superconductivity of the BSCCO tapes in the DC HTS power cable.

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